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On White Holes as Particle Accelerator

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Abstract—We analyze scenarios of particle collisions in the metric of a nonextremal black hole that can potentially lead to an ultrahigh energy $E_{\mathrm{c.m.}}$ in their center-of-mass frame. Particle 1 comes from infinity to the black hole horizon while particle 2 emerges from a white hole region. It is shown that an unbounded $E_{\mathrm{c.m.}}$ requires that particle 2 pass close to the bifurcation point. An analogy with collisions inside the horizon is discussed.

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1. INTRODUCTION

Several years ago, an interesting effect was discovered. It turned out that if two particles collide near a rotating extremal black hole, the energy $E_{\mathrm{c.m.}}$ in their center-of-mass frame can become unbounded [1]. It is called the Bañados-Silk-West (BSW) effect, after the names of its authors. Later on, this effect was generalized to nonextremal horizons [2], generic rotating black holes [3] and even nonrtotaing charged ones [4]. In all these cases it is implied that both particles move towards the horizon as usual for black holes.

Meanwhile, there are also scenarios with head-on collisions when one of particles moves away from the horizon. They were cursorily mentioned in Sec. II G of [5] for the rotating case, although the term "white hole" was not used there. A detailed coherent treatment of this type of scenario was performed in [6] where the role of white holes was stressed, and it was noticed that an unbounded $E_{\mathrm{c.m.}}$ appears even for the Schwarzschild metric. As is known, the space-time of an eternal black hole inevitably includes two regions, the black-hole and white-hole ones. In the scenario considered in [6], particle 1 moves towards the future horizon whereas particle 2 approaches the past horizon from the inner white-hole region. For nonextremal horizons (which is the subject of the present work) this means, in terms of R- and T-regions [7], that particle 2 passes from the expanding T-region to the R-region, whereas particle 1 moves within our R-region, as usual. This scenario works for generic particles, in contrast to the standard BSW effect, where fine tuning between the parameters of one particle is required, and is valid for generic eternal black-white holes.

In the present paper, we further analyze this scenario, describe the main features of the relevant trajectories and argue that there exists a close similarity between such a scenario and high-energy collisions inside the horizon.

Some reservations are in order. The existence of white holes is questionable. In particular, they can be unstable (see Sec. 15 of [8]). However, we can point out to at least three factors that support our motivation. (i) Many years ago, an interesting conjecture was put forward, according to which white holes can act as regions retarded in the expansion of surrounding matter in the Universe [9]. It is important that the corresponding scenario includes, in particular, collisions between particles that leave a white hole and those that move outside it corresponds just to our case. (ii) Typically, the structure of space-time includes alternation of R- and T-regions. For example, this happens for regular black hole, so-called black universes [10], the motion of self-gravitating shells [11], etc. (iii) Even if (i) and (ii) are not realized in practice in astrophysics, collisions of particles near white holes is an essential ingredient of the theory of high-energy collisions. Without this treatment, our understanding of the BSW effect and its modifications would remain incomplete. It is also worth noting that the energetics of white holes was discussed a long time ago but in quite a different context [12].

Throughout the paper, we use the units in which the fundamental constants are $G = c = 1$.

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